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TRANSACTIONS

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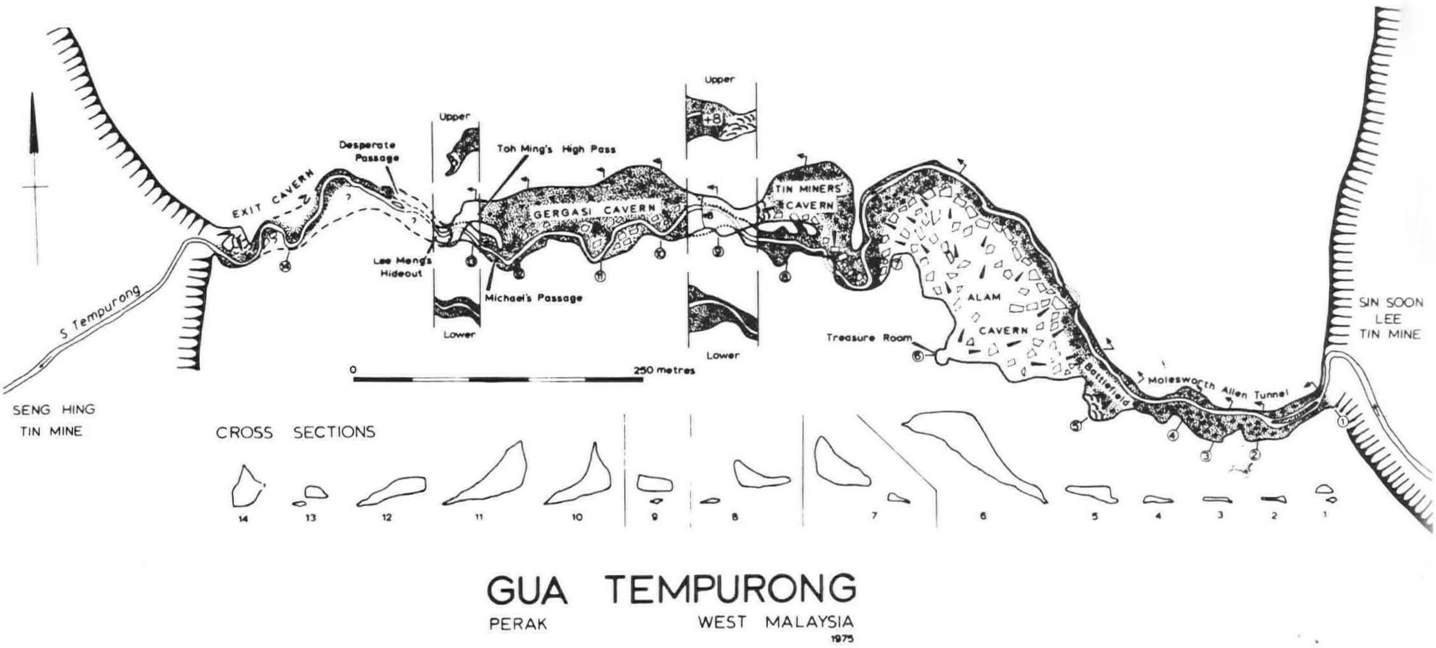

Malayan Karst

Fossil Human Tooth

Limestone Solution

Histoplasmosis in Jamaica

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CONTENTS

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KARST REGIONS AND CAVES OF THE MALAY PENINSULA, WEST OF THE MAIN RANGE

by J. Crowther

SUMMARY

In the humid and seasonally humid tropics of the Malay Peninsula, west of the Main Range, karst occurs in three localities, Selangor, the Kinta Valley, and the northwest. The limestones range in age from Ordovician to Triassic, are mainly metamorphic, and locally exceed 3000 m in thickness. The marbles of Selangor, the Kinta Valley and of Permian and Triassic outcrops in the northwest region are very pure and are exposed as tower karst forms. Dry caves, infilling with speleothems, guano and other deposits are numerous in such towers, but active vadose passages are absent, except where water is derived from allogenic sources. In contrast, Ordovician-Silurian limestones of the Setul Formation are less pure and form an extensive and deeply dissected range of hills, the Setul Boundary Range, in the northwest. Soils are deeper and caves are less well developed in strata with a high content of acid insoluble residue. The larger catchment area afforded by the Boundary Range, and the presence of less permeable, impure beds, enable vadose flow to be maintained in many lower cave passages.

INTRODUCTION

Outcrops of limestone occur at scattered locations throughout the northern half of the Malay Peninsula. Whilst they are neither extensive nor of high relief, they give rise to dramatic and highly distinctive topographic and sub-surface forms. Three principal karst regions, of differing lithology, morphology, and climate, may be identified to the west of the Main Range:

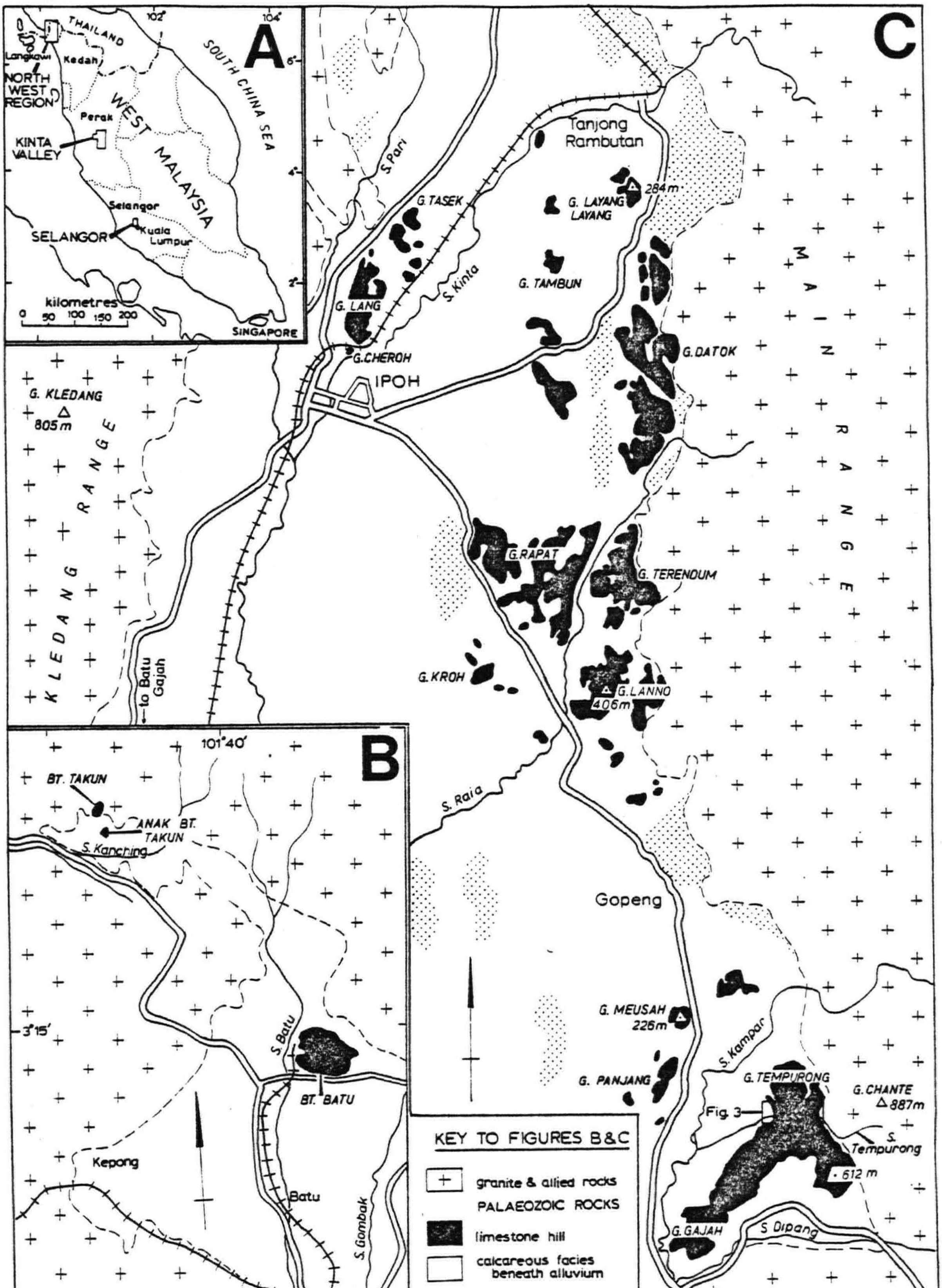
1. Selangor, north of Kuala Lumpur
2. Kinta Valley, Perak
3. Northwest Malaysia, i.e. northern Kedah, Perlis and the archipelago of Pulau Langkawi.

This paper is an appraisal of the present state of karst research in these regions (Fig. 1A).

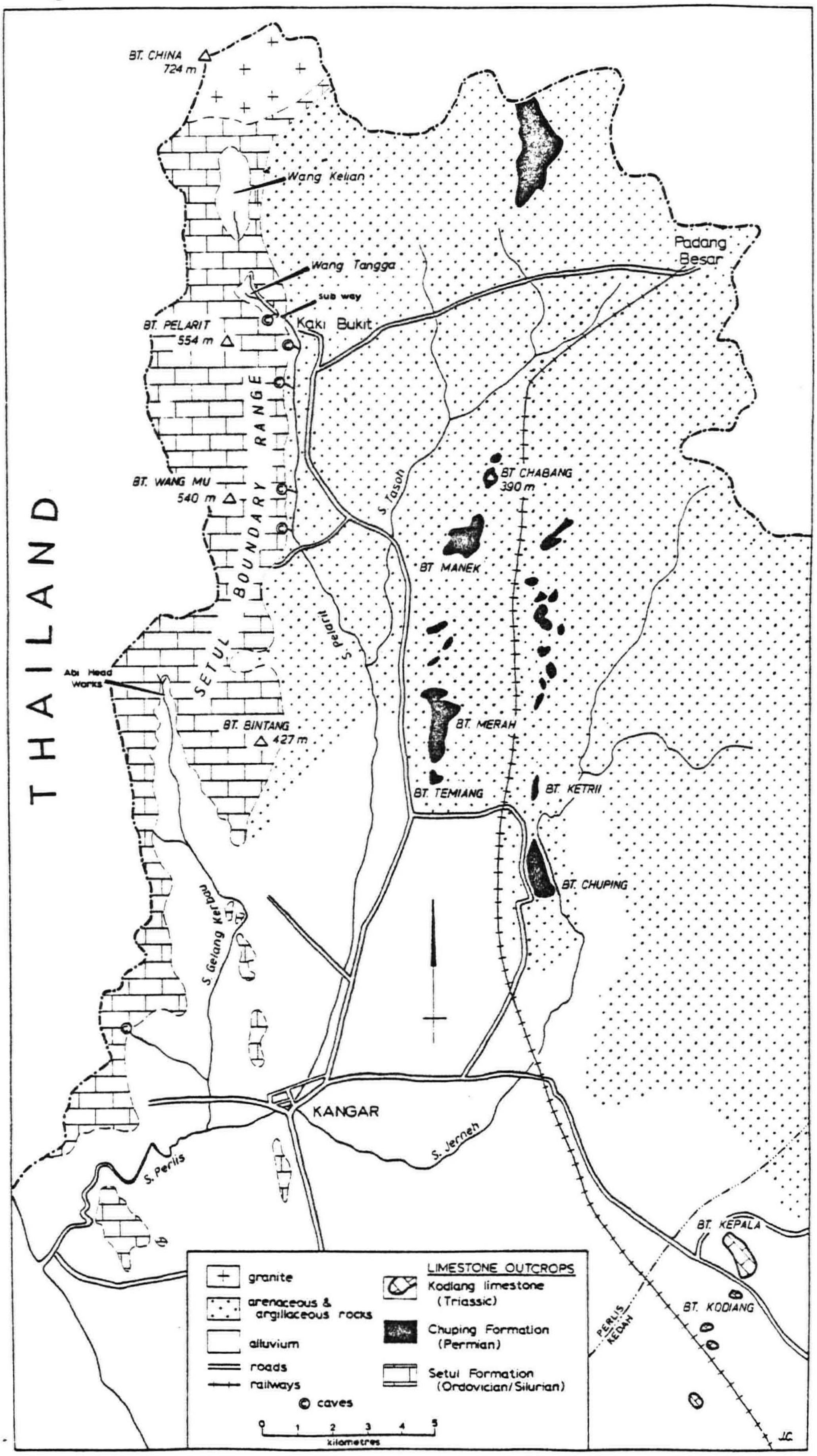
GEOLOGY

The Malay Peninsula forms part of a much larger structural unit, a cratonised block known as "Chersonesia" (Gobbett, 1973), which has evolved since Precambrian times through a series of stages related to the shifting margins of tectonic plates. During the Lower Paleozoic, the western half of the peninsula was occupied by an eastwards migrating geosynclinal sequence, subducting beneath a Precambrian landmass to the west (Jones, 1973). At this time, deeper basin environments alternated variously with stable shelf conditions. In the Cambrian period, the latter were associated with deltaic deposits, but deposition of limestone became dominant as sediment supply diminished during the Ordovician and Silurian. In the Kinta Valley, limestone deposition was continuous from Silurian to mid-Permian times. In the North West and further south in the Selangor region a major break in sedimentation occurred towards the end of the Devonian period, resulting from uplift, folding and possible granitic intrusion. The Upper Paleozoic saw the continuing eastwards migration of the westwards subducting trench, and by the end of the Carboniferous period it lay well clear of the Malay Peninsula (Hutchison, 1973). At some stage, possibly as early as the Carboniferous period, a second trench system developed to the west, migrating westwards and subducting eastwards beneath the peninsula. Further limestone deposition occurred as shelf conditions returned and locally, in Kedah, this continued through until the Upper Triassic. However, with the exception of this anomaly in northwest Malaysia, the late Triassic was a period of massive uplift and intrusive activity. At this time, the granites of the Main Range were emplaced and the country rocks were subjected to varying degrees of metamorphism. This marked the end of the geosynclinal stage in the Malay Peninsula, and the region has been above sea level since the Jurassic period. East-west compressive stresses have subsequently produced a series of broad north-south trending corrugations in the northwest (Jones, 1965) and many minor tear faults, with northwesterly strike, in the

Fig. 1. J. Crowther



A. Location map. B. Selangor region C. Kinta Valley



Northwest region

Table 1 Characteristics of limestone formations, west of the Main Range

	(1) KUALA LUMPUR LIMESTONE	(2) KINTA LIMESTONE	(3) KODIANG LIMESTONE	(4) CHUPING FORMATION	(5) SETUL FORMATION
Location	Selangor	Kinta Valley	North Kedah	Perlis and Langkawi	Perlis and Langkawi
Age	Silurian	Silurian to Permian	Triassic	Permian	Ordovician to Silurian
Estimated thickness (m)	1830[1]	>3000[2]	?	600[3]	1547[4]
Number of Samples	52[5]	72[6]	11[7]	25[8]	37[5]
CaO (%)	49.21 (27.16-56.70)	46.44 (26.43-56.28)	48.78 (31.92-55.72)	49.95 (31.64-56.56)	46.88 (28.45-53.06)
MgO (%)	5.40 (0.07-22.05)	8.81 (0.12-80.25)	5.33 (0.17-18.57)	4.10 (0.17-20.39)	3.10 (0.02-21.36)
Acid insoluble residue (%)	1.84 (0.01-14.20)	1.55 (0.05-12.00)	2.81 (0.10-8.20)	3.44 (0.10-26.20)	9.89 (1.90-42.29)

Sources:
1. Gobbett (1964)
2. Ingham and Bradford (1960)
3. Jones (in press)
4. Jones (1973)
5. Hutchison (1966); author
6. Ingham and Bradford (1960); Hutchison (1966); author
7. Alexander et al. (1964); Hutchison (1966)
8. Hutchison (1966)

Kinta Valley (Gobbett, 1971). Major wrench faulting occurred in the latter region between the Cretaceous and Oligocene, producing a complex set of second or third order joint/fault patterns (Stauffer, 1973). In general, however, the Cenozoic has been a period of continuous erosion under relatively stable climatic (Morgan, 1976) and tectonic (Stauffer, 1973) conditions and eustatic sea level changes have provided the only major disturbance in the geomorphic evolution of the region.

The characteristics of the main karst rocks are summarised in table 1. The limestones of Selangor and the Kinta Valley were recrystallised by regional metamorphism and are very pure, finely crystalline marbles of low porosity and high mechanical strength. Whilst calcite forms the major mineral, small amounts of magnesium are frequently present and dolomite may be locally dominant. The Kuala Lumpur Limestone series is composed almost entirely of carbonate, while the thicker limestone deposits of the Kinta Valley are frequently interbedded with argillaceous sediments. In both regions, the original bedding is often preserved and the rocks are variably dissected by joints and faults.

In northwest Malaysia, limestones of three different ages may be identified. The two youngest, the Kodiang limestone and the limestones of the Chuping Formation, are similar to those described above, but are slightly less pure. The oldest, the limestones of the Setul Formation, are thickly bedded and generally dark-grey in colour due to the presence of considerable detrital and carbonaceous impurity (Jones, 1965). The amount of acid insoluble residue, 9.89%, is significantly higher than in the other four limestones. Locally, where metamorphism has been slight, the original bedding and occasional bands of argillaceous and siliceous impurities are well preserved. The Setul limestones are mainly disposed on the eastwards dipping limb of a north-south trending anticline. Towards the anticlinal core the limestone is replaced by a calcareous phyllite. The latter, comprising lens-shaped nodules of carbonate enclosed by laminae of brown argillaceous material (Jones, in press), is exposed in the Gelang Kerbau Valley, near Abi Head Works. In this vicinity the limestones are notably less pure than in other parts of the Boundary Range.

CLIMATE

The three karst regions lie between 3° and 7°N. They have an equatorial monsoon type climate with uniformly high temperatures throughout the year (table 2). The Malay Peninsula comes under the influence of two major wind systems, the southwest monsoon from the Indian Ocean, and the northeast monsoon, originating in continental Siberia and following a course over the South China Sea. In both cases the air is moist and unstable (Dale, 1959) and humidity is continuously high. In Selangor and the Kinta Valley, rainfall is fairly evenly distributed throughout the year (table 3), the

Table 2 Mean Temperatures for selected stations[1]

STATION	HEIGHT, M.S.L. (m)	ANNUAL MEAN (°C)	MEAN MONTHLY MINIMUM (°C)	MEAN MONTHLY MAXIMUM (°C)	RANGE (°C)
Kuala Lumpur	34	26.2	25.8 Nov/Dec	26.8 May	1.0
Ipoh, Kinta Valley	39	26.4	25.8 Nov	27.1 Jun	1.3
Alor Star, Kedah[2]	5	26.6	25.7 Dec	27.3 Apr/May	1.6

1. Data from Dale, 1963
2. Closest station for which reliable temperature records are available, 35 km south of northwest karst region

Table 3 Mean monthly and annual rainfall totals for karst regions[1]

REGION[2]	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN
	MONTHLY MEAN (mm)												
Selangor	151	154	261	287	202	142	122	153	204	301	285	233	2495
Kinta Valley	194	158	238	285	231	145	131	173	220	309	300	259	2643
Northwest	52	55	105	166	178	158	181	197	256	266	242	104	1960

1. Calculated from records of Drainage and Irrigation Dept., Malaysia, 1961.
2. Based on records of long-established stations: Selangor (4 stations), Kinta Valley (4), Northwest (5).

mean annual totals being 2495 and 2643 mm, respectively. Precipitation maxima occur in April and October and correspond with the inter-monsoonal periods. In the northwest region, the mean annual total of 1960 mm is significantly lower and the rainfall has a more pronounced seasonal incidence. Of particular geomorphological and biological significance is the rainfall minimum from December to February. This may be exceptionally low. At Kangar, for instance, during the period from 1909 to 1958, no rain was recorded in January on five occasions, and in February on four. In all three areas much of the rainfall occurs as high intensity convectional storms of short duration. Storms greater than 25.0 mm are common (table 4), while those exceeding 100.0 mm may occur on average every two to three years.

Table 4 Frequency of rainfall events of given magnitude (1970-74)[1]

REGION[2]	AVERAGE NUMBER OF DAYS PER ANNUM WITH RAINFALL EXCEEDING: 1.0mm	25.0mm	50.0mm	100.0mm
Selangor	159	34	10	0.5
Kinta Valley	157	33	9	0.7
Northwest	126	24	7	0.4

1. Calculated from records of D.I.D., Malaysia
2. Based on 4 stations in each region

KARST GEOMORPHOLOGY

The karst regions have a long erosional history, dating back to at least the Jurassic. Although the limestones in all three areas were overlain by non-calcareous sedimentary rocks, these were mostly removed at an early stage and their effects are no longer evident in the landscape. This prolonged and uninterrupted period of karstification, under predominantly humid tropic conditions, is reflected in the surface topography and the underlying cave systems.

REGIONAL DESCRIPTIONS

1. Selangor

Natural exposures of the Kuala Lumpur limestone are restricted to three localities, Bt. Batu, Bt. Takun and Anak Bt. Takun (Fig. 1B). Of these, Bt. Batu is the best known and forms a prominent landmark 10 km north of Kuala Lumpur. It is an isolated tower, 1.3 km in areal extent, which rises abruptly to an altitude of 304 m from the broad alluvial plains of the S. Batu and S. Gombak, at 53-61 m. Bt. Takun (Plate 1, Fig. 1) and Anak Bt. Takun are located 8 km further north in an area drained by the S. Kanching. The limestones forming these three outcrops are continuous beneath the adjacent plains and are frequently exposed at the bottom of tin-mine workings.

The sides of the hills, in common with towers in the other two karst regions, generally take two forms:

i) precipitous rock walls, often exceeding 100 m in height, e.g. Bt. Takun,

or ii) steep slopes comprising accumulations of angular limestone blocks derived by rock fall from the free faces of high cliffs, e.g. Anak Bt. Takun. Despite their scree-like form, such slopes often have an almost continuous cover of mineral soil.

The first type is usually dominant. According to Jennings (1976) more than two-thirds of the undisturbed margin of Bt. Batu comprises tower walls. Of these sections, approximately one-sixth have cliff-foot caves, penetrating in some instances to a depth of 15 m. The latter features may be formed by sub-soil solutional processes (Jennings, 1976) but in many cases, alluvial swamp water, or stream action seems a more likely cause. Their frequency supports the view that they may be instrumental in tower karst development.

The cliffs are generally straight in plan and show much evidence of structural control. Since they are often vertical or overhanging, the water they receive comes either as condensation, run-off from exposed cliff tops, or as seepages from joint planes which intersect the cliff face. Solution may occur at the tops of the cliffs but evaporation and loss of carbon dioxide from films of surface water generally predominates, favouring re-precipitation. As a result, rock surfaces are coated with a uniform white patina of powdery calcite and adorned by spectacular stalactite forms which hang from projecting ledges on cliff faces.

The influence of geological structure is strongly reflected in the topography of the summits. Their surface is invariably highly dissected along solution-widened joint planes, and intervening blocks of more massive marble are highly pitted, sharply etched, and often pinnacle-like in form. Locally, the amplitude of relief may exceed 20 m. In common with large towers elsewhere in the peninsula, the surface of Bt. Batu is further broken by enclosed depressions and narrow, steep-walled corridors. The former vary from small, isolated features developed at the intersection of joint planes, to larger forms with flat floors at or near the level of the adjacent plains. In a number of cases, surface depressions connect directly with underlying cave systems via open vertical shafts. The purity of the limestone and resulting absence of continuous regolith cover, further accentuate the ruggedness of the relief.

Mineral soils are generally thin or even absent, but may occasionally penetrate the bedrock to depths of several metres along solution-widened fractures. Such soils are typically reddish-brown in colour, very friable, and of a slightly acid reaction, their acidity increasing in deeper soils with distance from the weathering front. Five samples from the summit of Bt. Takun had an average pH of 5.5 (range 5.0-6.3). Over much of the surface, however, soil is confined to patches of organic material which accumulate in poorly drained hollows and crevices on exposed rock surfaces. Five samples each of organic-rich mineral soil and decaying organic litter had pH values of 6.7 (range, 6-1-7.2) and 5.6 (range, 5.2-5.9) respectively.

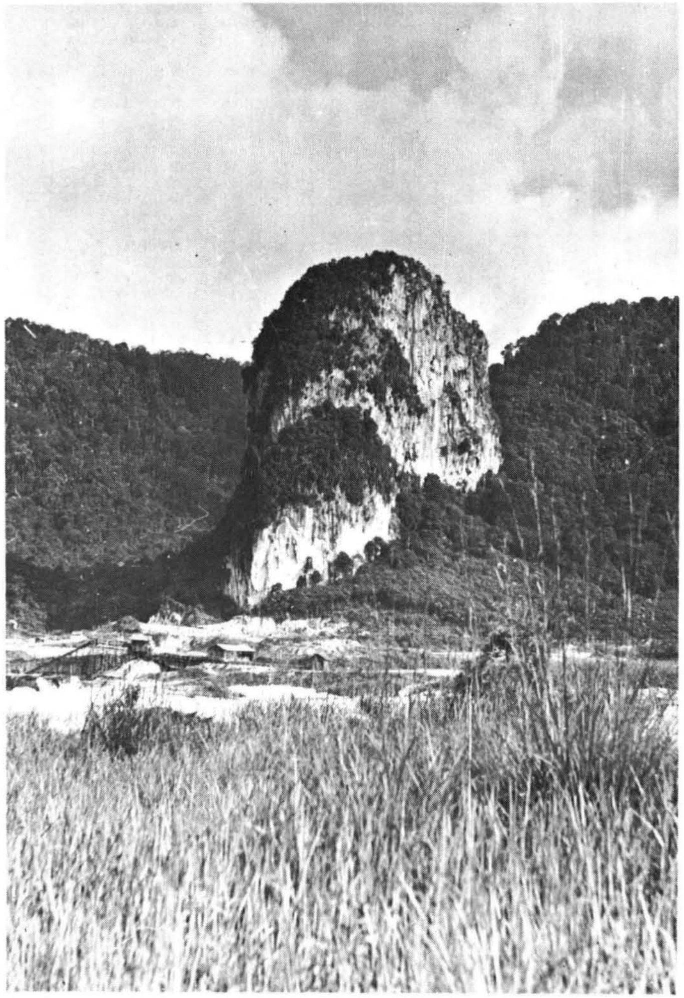
Lowland Dipterocarp Forest (rain forest) forms the climax vegetation at lower altitudes. *Hopea dryobalanoides*, of the family Dipterocarpaceae, has been recorded on Bt. Batu (Wycherley, 1971), but with few exceptions, dipterocarps are absent from the limestone hills both in Selangor and the Kinta Valley and tree-flora is of types characteristic of the understorey of tall lowland or undisturbed secondary forest. In more favoured localities on the summits and boulder-clad slopes, stunted and mis-shapen trees, typically of *Vitex siamica*, *Memecyclon* spp. and *Garcinia* spp (Henderson, 1939) form an irregular and discontinuous canopy. Elsewhere, on the summits and exposed cliffs, the bare rock surfaces support a wide variety of cremnophyte and calcicole species, *Boea* spp., *Chirita* spp., and *Monophyllaea* spp. being common.

2. Kinta Valley

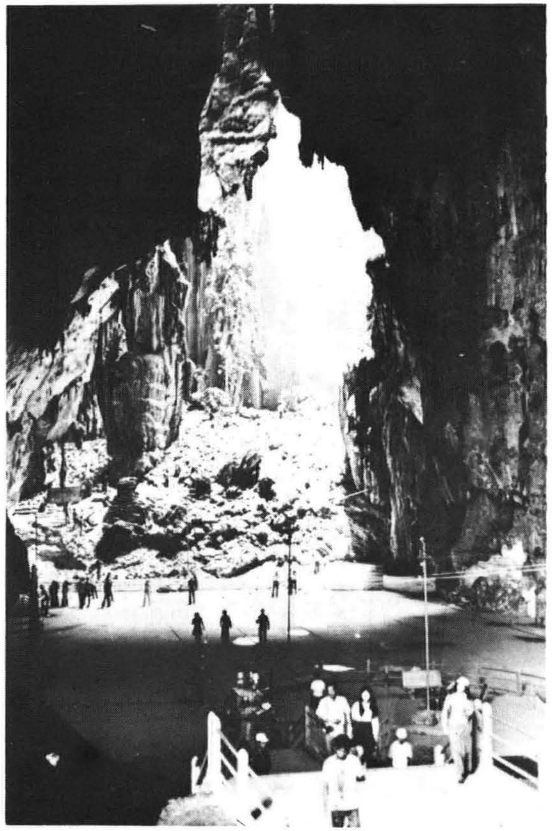
Outcrops of Kinta Limestone number more than fifty in Perak and occupy an area of almost 50 sq km. They are mainly concentrated down the eastern flank of the Kinta Valley (Fig. 1C). The G. Gajah-Tempurong Massif (612 m) forms the largest outcrop. It has been described more fully elsewhere (Crowther, 1978). Aerial photographs reveal clear, northwesterly, tectonic lineations in the form of the hills (Gobbett, 1971) and individual outcrops show marked structural control (Plate 1, Fig. 3). Surface topography, and soil and vegetation characteristics resemble those of the Selangor region. Enclosed depressions, known locally as 'wangs', occur frequently and in some cases exceed 1 km in length along their major axis.

In many places, the lowlands adjacent to the hills form part of the contemporary flood plain which, in the case of the S. Kinta, rises from a height of 21 m m.s.l. in the vicinity of Batu Gajah to 70 m near Tanjong Rambutan. Under such circumstances, cliff-foot caves and notches are often present within several metres of the hill-plain junction and locally rivers actively undercut the base of the towers. The lowlands elsewhere comprise the eroded remnants of an extensive, higher-level alluvial plain, the 'Old Alluvium' (Walker, 1956), which has been widely recorded to heights of 70 m. Evidence, summarised by Stauffer (1973), suggests the latter to be related to early- or mid-Pleistocene sea level fluctuations. A deep notch at 76 m on the eastern side of G. Tempurong would appear to be contemporaneous in origin.

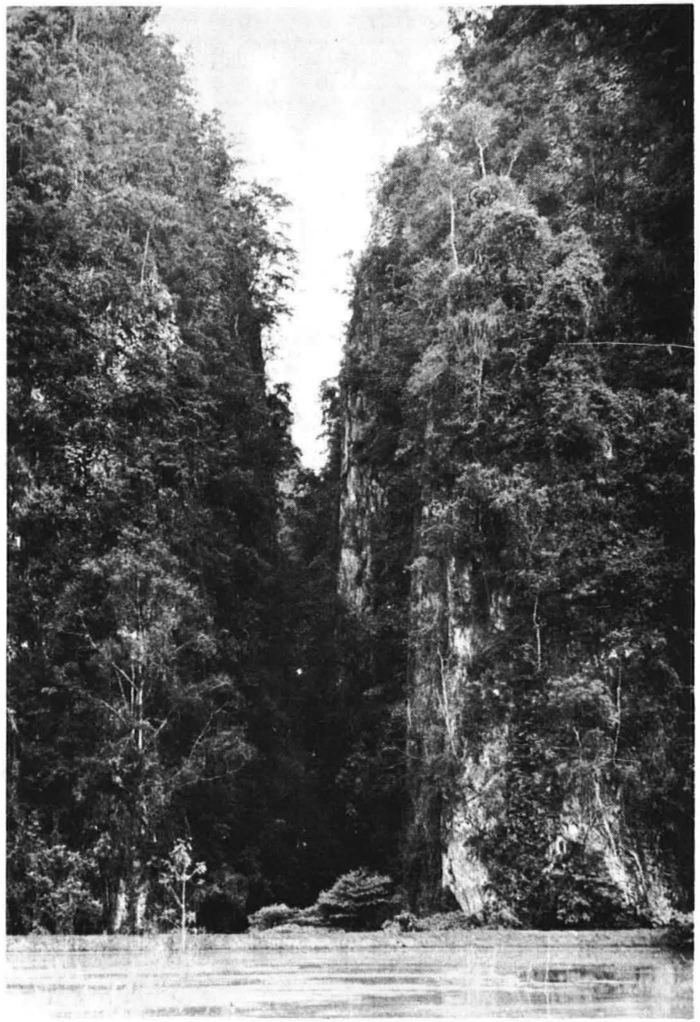
At locations where there is no evidence of recent undercutting at the base of the cliffs, notches are often present beneath the high-level alluvium at the junction between the sub-alluvial karst surface and the hills (Plate 2, Fig. 1). Although the present form of such tower walls suggests that there has been relatively little slope development since deposition of the Old Alluvium, scattered rock debris on the surface indicates that rockfall is still active. Several rockfalls have been recorded since the beginning of the century, notably in 1927, 1940 and in October 1973 at G. Cheroh, near Ipoh. In the last instance, a triangular slab of rock (Plate 2, Fig. 2), measuring 43 m in both height and basal length, averaging 6 m in thickness, and weighing approximately 24 000 tonnes (Shu



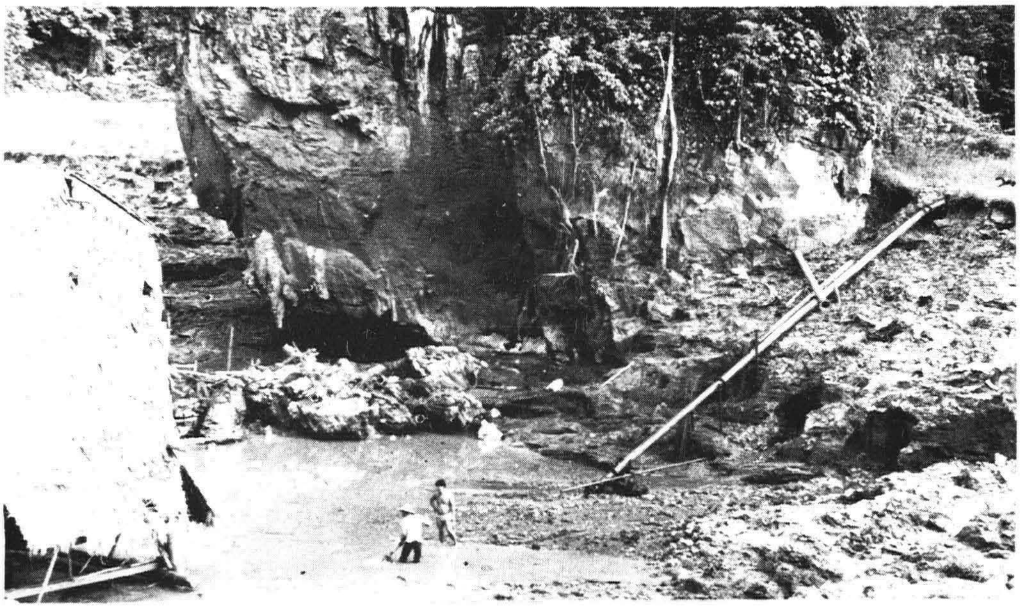
1. Bt. Takun, a tower 18km north of Kuala Lumpur, granite to the left and quartzite to the right.



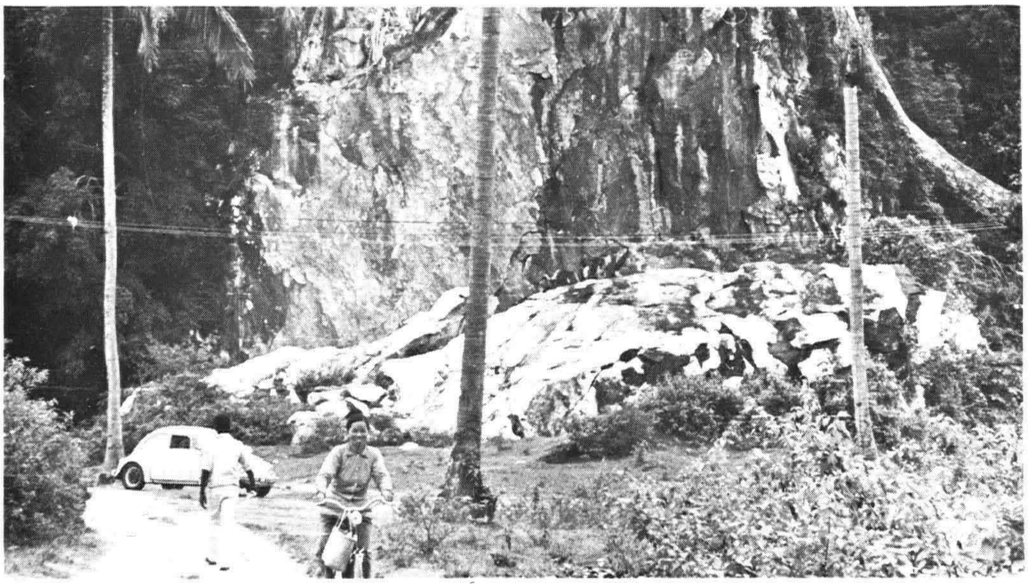
2. The main chamber and a shaft in Temple Cave, Gua Batu.



3. A joint-controlled corridor in G. Datok, Kinta valley, with a mining pool in the foreground.



1. Cliff-foot notches exposed beneath Old Alluvium in tin workings.



2. Rockfall which killed 50, G. Cheroh, near Ipoh.

3. Marine-cut notch above later sub-soil or swamp undercutting, Bt. Kepala.

and Lai, 1973), fell onto a longhouse killing about 50 people (Straits Times, 2nd Nov., 1973). Recent falls have also been reported at G. Kroh and G. Tasek.

3. Northwest region

Two distinct karst landscapes may be identified:

i) Tower karst

The Kodiang limestone and limestones of Chuping Formation give rise to tower karst forms similar to those previously described. Kodiang limestone is exposed in five towers along a narrow belt in northern Kedah (Fig. 2) and reaches a maximum height of 178 m. Outcrops of Chuping limestone are more numerous. In central Perlis they cover approximately 4 km^2 and occur along two distinct lines in a north-south trending synclinal trough. Bt. Chabang forms the highest summit at 390 m. Many of the hills are bounded by low coastal plains, less than 10 m in height, and their bases thus lie within the altitudinal range of Holocene sea level fluctuations. On the seaward side of certain towers, evidence of such changes is provided by the presence of cliff-foot caves with profiles (Plate 2, Fig. 3) identical to those of contemporary wave-cut notches in the adjacent islands.

Offshore, in the archipelago of Pulau Langkawi, outcrops of Chuping and Setul limestone occur frequently as isolated sea stacks. Most of the coastal cliffs are clearly products of former low base levels since, according to Hodgkin (1970), contemporary wave-cut platforms are absent or, at most, poorly developed, and the cliffs generally continue precipitously below sea level. In comparison, therefore, with the effect of the major eustatic sea level oscillations of the late Pliocene and Pleistocene, more recent fluctuations have been of insufficient magnitude or duration to influence significantly the tower karst on the mainland or the sea stacks of the adjacent islands.

ii) Setul Boundary Range

The Setul Boundary Range, comprising limestone of the Setul Formation forms an extensive range of hills along the western end of the frontier between Malaysia and Thailand. The outcrop is generally less than 5 km wide in Perlis, but is continuous over the border. The area is drained by the S. Pelarit and S. Gelang Kerbau. Relief decreases rapidly from north to south. In the north, Bt. Pelarit and Bt. Wang Mu reach heights of 554 and 540 m respectively, while near the coast, summits rarely exceed 300 m. Viewed from central Perlis the Boundary Range appears outwardly solid and imposing, with a plateau-like form. It is, however, deeply dissected by steeply cliffed ravines, dolines, and many large enclosed depressions. Of the latter, Wang Tangga, drained by the S. Pelarit, is the most spectacular. It is totally enclosed and access may only be gained via a 300 m walk-way, suspended some 5 to 10 m above the subterranean course of the river. The flat, alluvial floor of the depression, at an elevation of approximately 60 m, covers 0.7 km^2. The alluvial fill is derived from the exhumed granitic rocks of Bt. China to the north and its deposition was probably contemporaneous with that of the Old Alluvium of the Kinta Valley. Jones (in press) identified breaks of slope on the sides of Wang Tangga at approximately 76 m, and suggests that these correlate with cave levels in the Chuping outcrops. This evidence would support the presence of a previously higher base level of similar height and age to that widely recognised in the southern part of the Malay Peninsula (Burton, 1964; Walker, 1956).

Basal cliffs are infrequent and slopes are usually less steep than in the adjacent tower karst. Contrasts may be observed within the Boundary Range between outcrops of purer limestone, as around Wang Tangga, and those of less pure limestone, which occur in the Gelang Kerbau Valley (table 5). In the former area, soils are similar to those of the tower karst, while in the latter area, they are deeper, clay-rich, and often have lateritic concretions. In both areas, the comparatively gentle slopes and continuous soil cover support a high density of trees and in the Gelang Kerbau Valley timber is commercially exploited.

The flora in the northwest region shows strong affinities with that of Burma and Thailand. Species of dipterocarp, better suited to the shallow soils, with their low water holding capacity, and to the more seasonal precipitation regime, are far more common. *Hopea ferrea*, *Pentacme siamensis* and *Shorea talura* are locally very common, while *Hopea helferi*, *Hopea latifolia* and *Shorea sericeiflora* occur where soils are deep (Wyatt-Smith and Panton, 1963). Unlike the flora of Selangor and Perak, most trees

Table 5 Soil and vegetation characteristics of two contrasting plots (10 x 30m) in the Setul Boundary Range

	WANG TANGGA	GELANG KERBAU VALLEY
Altitude (m)	180	189
Slope angle	35^{o}	32^{o}
Acid insoluble residue (%)	2.35	9.65
Soils:		
Depth (cm)	21.1[1]	43.6[1]
pH[2]	5.96 (5.70-6.02)	5.50 (5.4-5.6)
Bulk Density[2] (g/cm^3)	0.82 (0.72-0.94)	1.26 (1.14-1.33)
Vegetation:		
Tree[3] density (No./ha)	1150	1166
Trees exceeding 100 cm, g.b.h. (No./ha)	109	233

1. Average of 90 measurements
2. Average for one soil profile in each area, range given in parentheses
3. Trees exceeding 15 cm, girth breast height (g.b.h.)

in the northwest are semi-deciduous in character and lose their leaves in January and February. Soil moisture deficits of the magnitude and duration experienced at this time (Nieuwolt, 1965) may, in addition, lower the levels of micro-biological activity in the soil and thus considerably reduce carbon dioxide production. Such effects, and their possible geomorphic significance, are currently being investigated by the author.

CAVES

With the exception of the less pure members of the Setul Formation, the limestones in all three areas are massive, mechanically strong and are able to support large caverns. Older, higher level cave passages are generally well-preserved and may occur several hundred metres above the surrounding plains. Lower, more recently active caves in certain cases exceed 80 m in height and 100 m in width. A clear distinction may frequently be made between the morphology of the upper and lower sections of individual caves. The upper parts are usually straight in plan, guided by major rock fractures. Their walls show little evidence of concentrated stream action and are almost invariably indented by large, shallow scallops, often more than 1 m in length. These characteristics are indicative of former phreatic conditions and it seems probably that most solutional enlargement would have occurred nearer the surface of the water-table where flow is generally of higher velocity. Evidence that such solutional processes are still active below the water-table is provided by the high frequency of land subsidence in the Kinta Valley. This phenomenon, according to Chong, F.S. (Pers. comm.), is caused by collapse in the sub-alluvial karst where the roofs of caverns are weakened by solution. The lower parts of the caves exhibit features typical of vadose conditions. They have pronounced horizontal grooves and undercuts in section, and are sinuous in plan.

The lower cave passages of the Setul Boundary Range are the only caves with permanent underground streams. Elsewhere in the peninsula, water-tables in the thick, almost uninterrupted, beds of limestone are generally below the level of the adjacent plains and the catchment areas afforded by the tower karst hills are too small to support authigenic vadose flow. Caves in these outcrops are gradually infilling with speleothems, bat guano and other cave deposits.

1. Selangor

i) Gua Batu

Gua Batu (= Batu Cave), undoubtedly the best known of all Malaysian caves, is located at a height of 92 m on the southern side of Bt. Batu (Plate 1, Fig. 2). It comprises two separate caves: (1) Temple Cave, which since 1891 has been the site of the Sri Subramania Swamy Temple, the principal shrine of the Hindus in West Malaysia (Veeriah and Wycherley, 1971), and (2) Gua Gelap (Dark Cave) which comprises five interconnecting caverns, totalling almost 1.5 km in length. Considerable sections of the latter have recently been opened to the public and are paved and illuminated. A detailed survey has been published (Heynes-Wood and Dover, 1929).

Gua Batu is typical of the caves in tower karst. It is rectilinear in plan. The caverns are straight, parallel-sided and, in Gua Gelap, terminate in sheer bedrock walls. They are between 10 and 40 m in width and meet at pronounced angular junctions. The walls are indented by shallow scallops and blind passages, and in places show evidence of vadose action. The roof is very irregular and marked height discontinuities occur, particularly at the junction of the major caverns. Broad arch-like forms are common in the smaller passages, while structurally controlled, slit-like forms occur in the roofs of higher sections. Locally the roof exceeds 80 m in height and in several places it is breached by open shafts or chimneys, the largest being 30 to 40 m in diameter. These connect directly with the top of the hill and coincide with the line of a transverse northwest-southeast trending ravine. In detail, however, these features are independent of and appear to pre-date the present surface topography. Their formation and role in the development of the cave is problematical. The chimneys provide the only visible inlets into the cave system, but do not always occur near the end of the caverns. It is difficult, therefore, to conceive that water from these sources could have beenresponsible for solutional enlargement of the necessary scale unless other outlets previously allowed the throughflow of large volumes of water. The irregular floor of the cave comprises undetermined thicknesses of guano and angular rock debris, and the bedrock walls are frequently covered by extensive deposits of secondary calcite. Flowstone and dripstone deposits are particularly prominent. One column in Temple Cave, for instance, is 6.5 m in diameter and 18 m in height. It seems probable that these superficial covers conceal passages formerly continuous and developed contemporaneously with those extant today and that the chimneys formed an integral part of such a system. Certain smaller shafts may, however, postdate the main period of cavern enlargement and be a product of collapse rather than solution.

ii) Gua Anak Takun

Gua Anak Takun is the only other noteworthy cave in the region. Its entrance lies at the base of a cliff at the eastern side of Anak Bt. Takun. The passages are generally low and in contrast with most caves in the peninsula they are wide in relation to their height. Gobbett (1965) noted Gua Anak Takun as an example of an horizontal cave developed in vertically bedded limestone. However, the depth of soft mud and guano which form the present floor of the cave is not known and it is possible that the bedrock floor is at considerable depth.

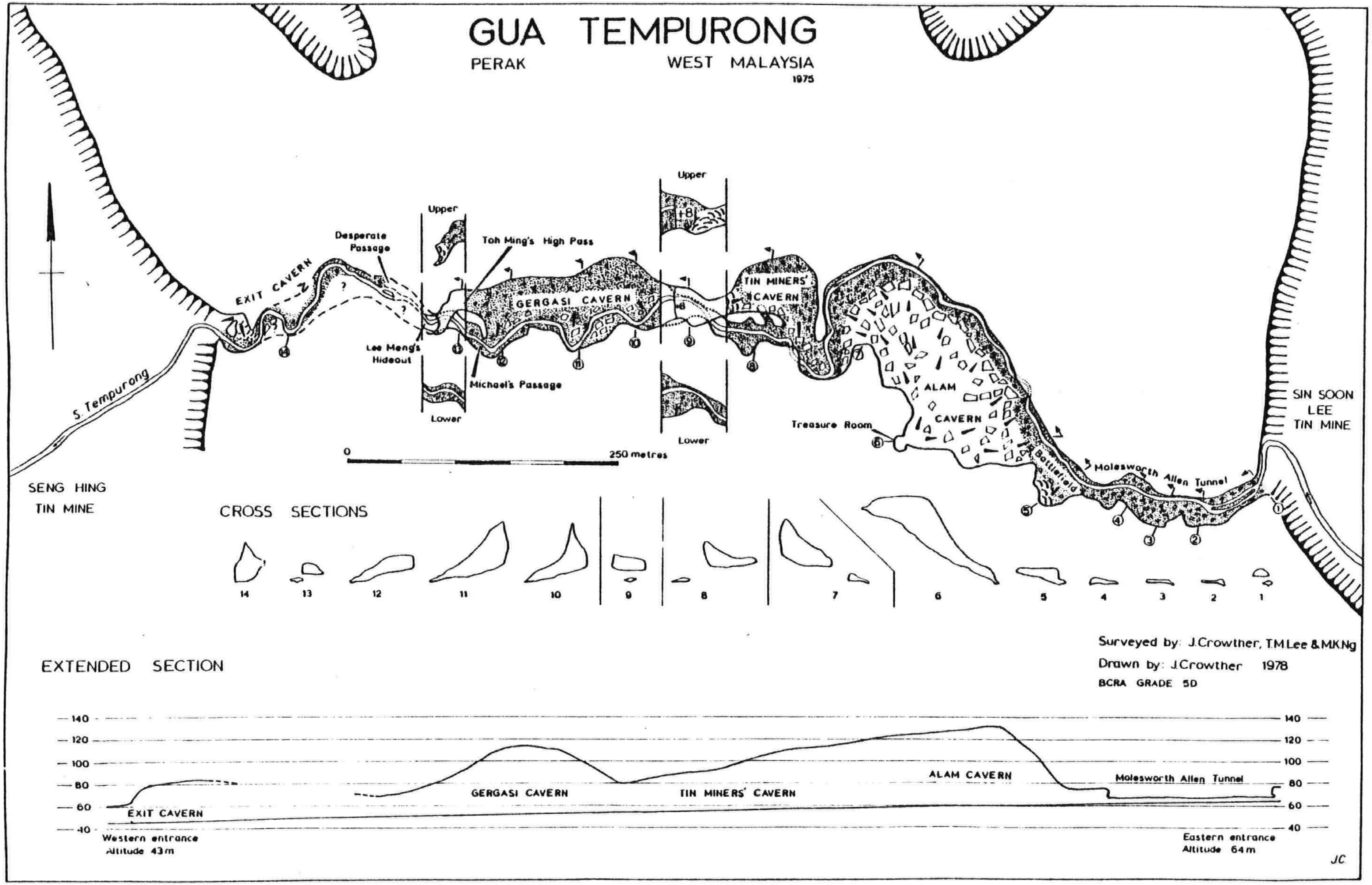
2. Kinta Valley

Few hills in the Kinta Valley are without cave systems and in many outcrops openings may be seen at several different levels. The caves range from small notches at the base of cliffs to larger forms with characteristics similar to those of Gua Batu. The limestone towers are of insufficient size to maintain vadose stream flow and even the largest tower, the G. Gajah-Tempurong massif, has no permanent authigenic underground flow. Streams of allogenic origin do, however, pass through the following outcrops:

i) G. Kroh - a small stream rising on the alluvial plain, cuts through the southwestern corner of the hill in a small passage, 200 to 300 m in length.
ii) G. Lanno - a low natural passage, almost 500 m in length, which has been artificially widened to accommodate a water pipeline.
iii) G. Tempurong - a stream, rising on Gunong Chante in the Main Range follows a 1.5 km east-west course through the hill.

The last, known as Gua Tempurong (Fig. 3), forms the largest and most spectacular cave system in the Kinta Valley. A detailed description has been published elsewhere (Crowther, 1978). The central sections of the cave comprise three caverns of enormous dimensions. Alam Cavern, the largest, is more than 130 m wide and reaches a maximum height of approximately 72 m. The upper part of these caverns are straight in plan and, like the surface topography, are guided by northwest-southeast structural lineaments.

Fig. 3.


GUA TEMPURONG
PERAK
WEST MALAYSIA
1975
Desperate Passage
Toh Ming's High Pass
Upper
Lower
EXIT CAVERN
GERGASI CAVERN
TIN MINERS' CAVERN
ALAM
CAVERN
Lee Meng's Hideout
Michael's Passage
Treasure Room
Battlefield
Moleswocth Allen Tunnel
SIN SOON LEE TIN MINE
S. Tempurong
SENG HING TIN MINE
0
250 metres
CROSS SECTIONS
14 13 12 11 10 9 8 7 6 5 4 3 2 1
Surveyed by: J.Crowther, T.M.Lee & M.K.Ng
Drawn by: J.Crowther 1978
BCRA GRADE 5D
EXTENDED SECTION
140
120
100
80
60
40
EXIT CAVERN
GERGASI CAVERN
TIN MINERS' CAVERN
ALAM CAVERN
Molesworth Allen Tunnel
Western entrance Altitude 43m
Eastern entrance Altitude 64m
JC

They are contiguous, but have no visible outlet. As in Gua Batu, former passages may have collapsed or be blocked or buried by cave deposits. In contrast, the lower parts, within 15 m of the stream, are continuous throughout the entire length of the system and exhibit a meandering pattern. Stream-cut notches recur at heights of 3.5 and 15 m above the present channel and in places the walls are undercut to depths of 30 to 40 m. It is interesting to note that the highest notch at the eastern entrance is at 79 m m.s.l., an elevation which corresponds closely with that proposed for the sea level maximum of the early- or mid-Pleistocene. The river bed comprises sands and gravels of unknown depth and in several places alluvial fill occurs to heights of 8 m above the present channel. These deposits may be contemporaneous in origin with the Old Alluvium.

3. Northwest region

i) Tower karst

Caves in the tower karst are similar to those in Selangor and Perak. They are all dry, often at heights well above the surrounding plains, and some, notably in Bts. Chuping, Kepala and Marek are particularly large. Many connect with sink holes on the summit slopes of the hills (Jones, 1965).

ii) Setul Boundary Range

Caves are not ubiquitous throughout the Boundary Range and are poorly developed in beds with high percentages of impurities. Near Abi Head Works, for instance, there are several karst springs but no penetrable caves have been found. Elsewhere, in purer limestone, caves are widespread. They occur at all altitudes up to 400 m and according to Jones (1965) have been followed to depths of 46 m below sea level.

In contrast to caves in the tower karst, their form is largely controlled by sedimentary structures. In plan, they comprise extensive networks of passages, guided by major bedding planes with dominant north-south strike. They rarely exceed 7 m in width or 10 m in height, and their walls are often irregular due to marked micro-variations in the erosional susceptibility of the bedrock. Lower caves, particularly those in the northern part of the outcrop with entrances near the level of the adjacent plains contain large quantities of alluvial fill. This occurs in pockets, often exceeding a depth of 10 m, and completely blocks many smaller passages. Bukit China is the likely source, but the age of the deposits is not known. The alluvium is stanniferous and, in consequence, many passages have been considerably modified by mining activity. In one cave, immediately inside Wang Tangga, the working face is more than 2 km from the entrance.

The extent of the limestone outcrop combined with the presence of less permeable, impure beds in the eastward dipping strata, enables permanent streams to be maintained in a number of the caves. Notable examples, shown in Fig. 2, occur in Wang Tangga and along the edge of the main eastern escarpment in a belt extending 7 km south of Kaki Bukit. Apart from stream flow, bedrock seepages are more numerous and have higher discharges than those in tower karst. In the Wang Tangga subway, for instance, one active stalagmite formation is 25 m long, 8 m wide, 10 m high, and is covered by tiers of rimstone pools, 5 m long, 3 m wide, and more than 1 m deep. Features of this scale do occur in other regions, e.g. in Gua Tempurong, but they are mainly relic forms.

CONCLUSIONS

The karst regions of the Malay Peninsula, west of the Main Range, exhibit a sufficient diversity of lithology, morphology and climate to provide an ideal area for geomorphological investigation. Despite this, the limestone outcrops are poorly known and research undertaken has mostly been descriptive or theoretical, lacking in substantive measurement of either form or process. There have, for instance, been no morphometric analyses of the surface topography and no studies of solution processes or weathering rates. Equally, there is a paucity of speleological research and of that undertaken much has focussed upon the ecology (Bullock, 1965; McCLure, 1961, 1965; Dunn, 1965) and archaeology (Peacock, 1965) of the caves rather than geological, geomorphological or hydrological aspects. It is perhaps significant that in 'The Science of Speleology' (Ford and Cullingford, 1976), only three sentences are devoted to Malaysian caves and those are concerned with flora and fauna.

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GLOSSARY OF MALAY WORDS

anak bukit	hillock	gunong (G.)	mountain
bukit (Bt.)	hill	sungai (S.)	river
gua	cave		

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LIMESTONE SOLUTION ON BARE KARST AND COVERED KARST COMPARED

by J.N. Jennings

ABSTRACT

Monitoring of an artificial bare rock small catchment and an artificial soil-covered one at Cooleman Plain, southern New South Wales, over a 2-year period has shown that the limestone removal rate of the former to be nearly twice that of the latter. Higher ionic concentrations in the soil catchment throughflow are outbalanced by its transpirative and greater evaporative water loss. Though this result is thought to be within the range of natural conditions at this karst, it is far from being representative. Nevertheless the experiment draws attention to the need for improved measurements of this kind in appropriate climates to ascertain the differential role of evaporation in the surface mosaics of many karsts.

Study of limestone solution has tended to concentrate on whole catchments and smaller scale components such as the chemical effects of overland flow, infiltration and throughflow have been neglected. Trudgill (1976) has pointed to the horns of the dilemma facing the would-be investigator who has 'either to experiment in artificial situations where at least the conditions can be measured; or to experiment in essentially natural conditions where the processes are harder to define and the conditions more difficult to measure'. In the experiment described here, the worst of both of these worlds may have prevailed. Yet the ragged results suggest an unexpected effect of importance in the relative performance of bare and covered karst, even it must needs be confirmed or denied by more rigorous procedures.

The overall temporal and spatial patterns of limestone solution of a small catchment at Cooleman Plain, New South Wales, were established crudely by monthly observations from April 1965 to March 1969. Between April 1969 and April 1977, these studies were continued on a more detailed basis, including continuous automatic observation of some variables. Many investigators have maintained that the bulk of limestone solution takes place at and near the ground surface and the earlier results from Cooleman Plain had supported this (Jennings, 1972a, b). Therefore some aspects of the solution in this superficial zone were pursued further by means such as limestone tablets (Jennings, 1977) and through more regular measurement of cave drips. One matter of importance in this zone is the relative performance of bare and covered (especially subsoil) karst.

Unfortunately, a prolonged search for natural catchments of a few square metres, which could conveniently be monitored, was unsuccessful largely because of the high frequency of joints everywhere. Small soil covered areas surrounded by bare rock divides and with natural outfalls were exceedingly rare and lifting of the soil in the few instances found revealed that in their cases also there was water loss down joints beneath the soil. Therefore two artificial small catchments were made on suitable outcrop free from joints, one left as bare rock and one covered with soil. It was originally intended to replicate them but early difficulties in managing the first two discouraged this.

EXPERIMENTAL DETAIL AND DIFFICULTIES

A bare rock catchment of 2.5 m^2 was monitored from 11 April 1975 and a soil catchment of 3.8 m^2 from 22 May 1975 to a common closing date of 1 June 1977. They were sited on a solution-rippled but joint-free rock surface with a convex slope of 5^o at the top and 35^o at the bottom but the soil catchment was closed off where the slope reached 15^o. Water was led off through filters from the lowest corner at the rock level by plastic pipe to sets of 54 litre plastic drums connected by siphons. Completely full drums were found to lose nothing by evaporation so loss from storage in this way is considered small. Initially the catchments were enclosed by polystyrene foam walls encased in heavy duty plastic sheet which was sealed to the rock by plastic cement. The grey bare rock appeared devoid of vegetation but closer examination revealed minute scattered lichens. This is generally the case with rock outcrops at Cooleman Plain, where absolutely bare rock is only found where soil erosion has recently stripped off a former soil cover. The soil catchment was constituted by removing the top 25 - 30 cm from an area of shallow rendzina soil in a nearby depression in large blocks and replacing them over the chosen site with the minimum possible disturbance to soil blocks. There were no rock fragments visible in the soil. A barrage of limestone blocks was placed around the polystyrene walls to protect them but also in the case of the soil catchment to reduce excessive evaporation round its margins.

Many things went wrong. On one occasion, wombats burrowed into the soil and scattered some of it onto the adjacent bare rock catchment. Marsupials, not necessarily wombats, ate parts of the walls. Frost lifted the cemented sheet and caused leakage. Therefore much of the walls was replaced by galvanised iron sheet, bolted as well as cemented down. On another occasion the feedpipe from the soil catchment was fractured by a wild horse which at the same time overturned collecting drums. Leaves and dust blown over the filter blocked the rock catchment drainage pipe more than once. Underestimation of the likely water yield between visits led to overflow of the collecting systems. In the end low temperatures rendered the plastic drums too brittle for further use and this was the final touch calling the experiment to a halt.

Because of comparative inaccessibility, the catchments were visited at irregular intervals of 6 to 43 days, averaging 23 days. All measurements for which there arose any doubt for the reasons given above were rejected from the analysis. Of the 32 observation periods for the rock catchment, data were as a result incomplete on 9 occasions, whereas this was the case with 7 of the 29 periods for the soil catchment. For only 19 periods were full data obtained from both catchments simultanously, the longest sequence without a break comprising 8 periods over a period of 9 months.

In the field, discharge (runoff in the case of the rock catchment, throughflow in the case of the soil catchment), temperature, pH and specific conductivity were measured. The total rainfall at the site between visits was also determined with a standard rain gauge. No precautions were taken about evaporative loss from the gauge or about snowfall; underestimation from these causes is thought to be small. In the laboratory, Ca^{++}, Mg^{++} and HCO_3^- were the routine chemical analyses but on a few occasions a wider range of ions (Na, K, Cl, SO_4) was determined, which demonstrated that the water was almost entirely a bicarbonate water.

RESULTS

Fig. 1 a, b and c show the daily rainfall and daily discharges as averages between observation periods. The lack of any marked seasonality in rainfall is reflected in rock catchment runoff whereas there is to a degree a seasonal rhythm of low summer - high winter throughflow present with the soil catchment. Despite this the product moment correlation of average daily discharge with average daily rainfall is stronger in the case of the soil ($r = 0.75$, $p = 0.0001$) than the rock catchment ($r = 0.51$, $P = 0.019$).

The rock catchment yielded 795 mm of discharge over a broken observation period of 504 days when rainfall totalled 1432 mm. Thus the overall efficiency was 56% but different observation periods gave efficiencies ranging from 11 to 100%. The winter months gave a figure of 46% whereas summer gave 81%. Possibly the intensity of falls is paramount, heavy storms losing little by evaporation whereas drizzles do.

The soil catchment was less efficient with a value of 12%, yielding 184 mm over 532 days when rainfall amounted to 1516 mm. The efficiency over observation periods varied from 0% to 36%. In this case, the lower efficiencies occurred mainly in summertime (mean 8%) and the higher ones in wintertime (mean 15%). These figures are in error to an unknown amount by breaks due to experiment failure on account of possible changes in soil storage. Over a long period soil storage can be neglected because any difference between start and finish in soil storage is small in relation to throughput but the breakdowns isolated four short periods of 12, 14, 15 and 61 days where this may not have applied.

The low efficiency of the soil catchment must be due to transpiration and enhanced evaporation compared with the rock catchment and there can be no doubt that the building up of the soil above the bedrock surface must have exaggerated loss by evaporation. This effect can only have been partly mitigated by the rock barrages placed around the catchment.

g

f

e

d

c

b

a

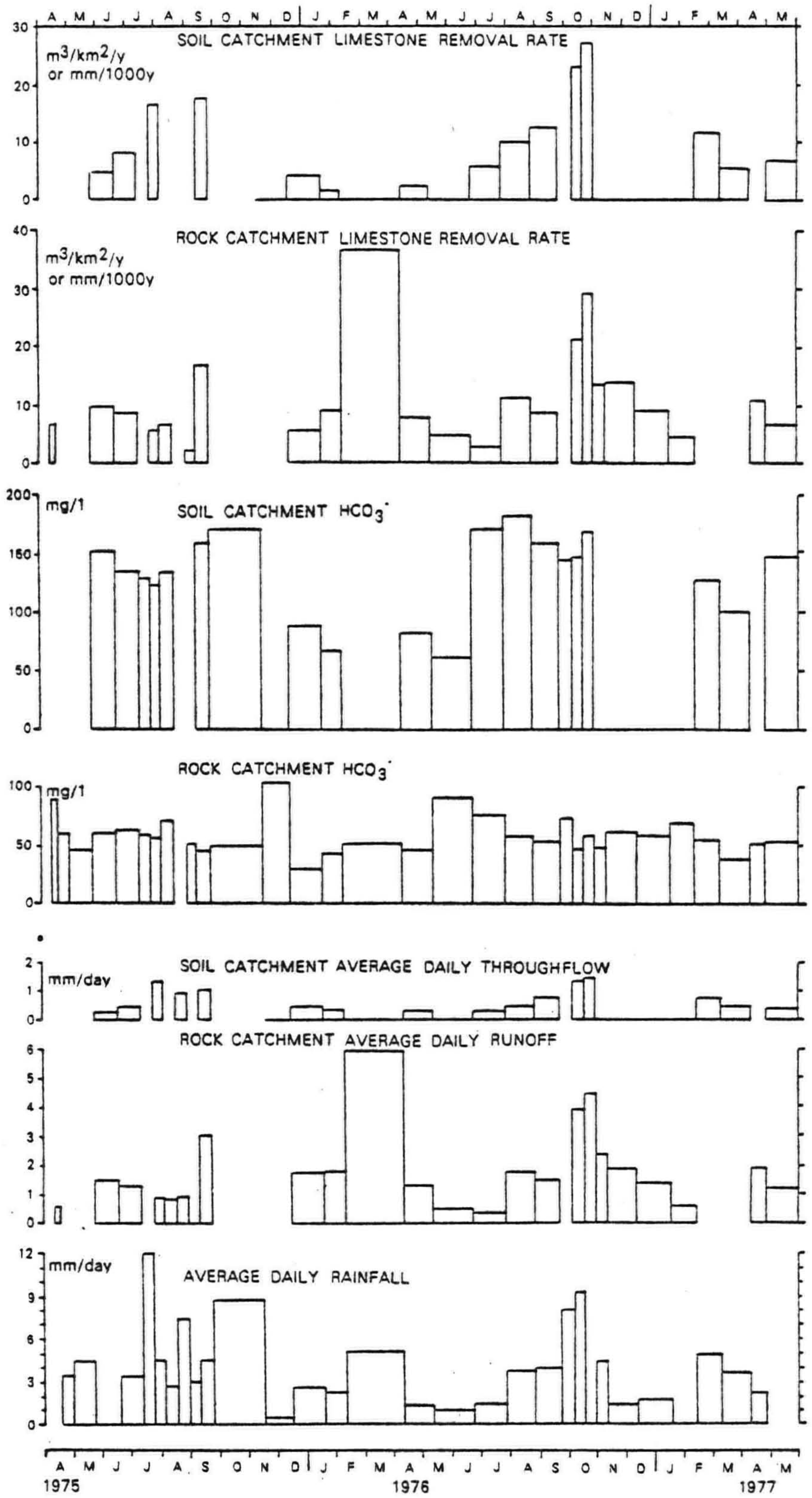

Fig. 1. Bar graphs of results from artificial rock and soil catchments from Cooleman Plain, N.S.W. Blank spaces represent observation periods when no determinations were available owing to experimental failure. Lines represent periods when the soil catchment yielded no throughflow although the collection system was working correctly.

Although there are patches of soil occurring naturally in a similar way to the artificial soil catchment at Cooleman Plain as was witnessed by parallel yellowing of grass and herb covers in both at times of water stress, nevertheless most of the Plain stayed green at such times so that an extreme condition has been measured at the artificial site.

The efficiency of the whole Cooleman Plain catchment of 52 km^2, of which only 29% is of limestone, was estimated for the years 1965-9; the most comparable years in terms of rainfall to the period of the artificial catchment experiment were 1966-7 with 72% and 1968-9 with 48%. The bare rock catchment falls readily into place in this overall picture but the soil figure, which applies to more of the limestone area than does the rock catchment one, appears to be low, consistent with the view that the soil catchment was subject to greater evaporative loss than is common over the soil covered part of the limestone plain.

Table 1 Ionic Concentrations

		Ca^{++}		Mg^{++}		Total hardness*		HCO_3^-	
	n	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Rock catchment	31	16.2	(5.5)	2.5	(0.7)	49.0	(13.7)	58.7	(15.6)
Soil catchment	20	40.2	(11.3)	3.0	(0.9)	110.8	(29.4)	131.6	(29.4)

* as $CaCO_3 + MgCO_3$

Table 1 shows the much higher solute contents of the soil throughflow compared with those of the rock runoff. The HCO_3^- from the rock catchment has an inverse Spearman rank correlation with the average daily runoff ($r = -0.55$, $P = 0.006$) and also with daily average rainfall ($r = -0.40$, $P = 0.037$). The Ca^{++} only shows this inverse relationship significantly with average daily rainfall ($r = -0.43$, $P = 0.038$) but the total hardness repeats the HCO_3^- pattern (with average daily runoff, $r = -0.43$, $P = 0.042$; with average daily rainfall, $r = -0.40$, $P = 0.036$). This suggests that a part of the variance in concentration is to be explained by transit time, high rainfalls and high runoffs being likely accompaniments of high intensity storms, which would more rapidly collect and flow off the rock surface with less opportunity for solution and for evaporation which might concentrate any solution already achieved. On the other hand one must recognise that increased turbulence due to more rapid flow would conversely promote solution (Weyl, 1958). It is not surprising that most of the variation remains unexplained statistically.

The soil catchment behaves differently. The Ca^{++} has a direct rank correlation with the average daily throughflow ($r = 0.51$, $P = 0.043$) as has the total hardness with identidal figures and an inverse product moment correlation with temperature ($r = -0.58$, $P = 0.047$) and so has total hardness ($r = -0.56$, $P = 0.040$). The hypothesis which suggests itself to explain this is that, when water availability is low, plant and microbial activity is also slight with reduced CO_2 production. Water availability is reduced by evaporation accompanying higher temperatures as well as by the actual precipitation. Since transit times are found to be longer with the soil catchment, there is also the question whether saturation is reached and whether the matter is affected by the inverse relationship of calcium equilibrium concentration with temperature. Unfortunately pH was not measured with sufficient precision for satisfactory determination of such parameters as SATCAL and P_{CO_2}. In any case the pH and temperature actually measured will differ from those at the moment of limestone solution because of the storage till the end of the observation period. In these circumstances a Picknett (1972) graph (Fig. 2) will be used as a rough guide. This suggests that soil throughflow when collected was rarely at saturation levels whilst with the rock catchment runoff this was the case rather more times but still infrequently. In further support of this, the mean calcium hardness of the soil throughflow was 102.4 mg/l with a mean temperature of 10°C; this is below the open system or aerobic solubility saturation level of 130 mg/l for 10°C and a CO_2 value of 0.45% (the mean of very many determinations of soil CO_2 at Cooleman Plain). Again most of the variation in concentration of the discharge remains unexplained statistically.

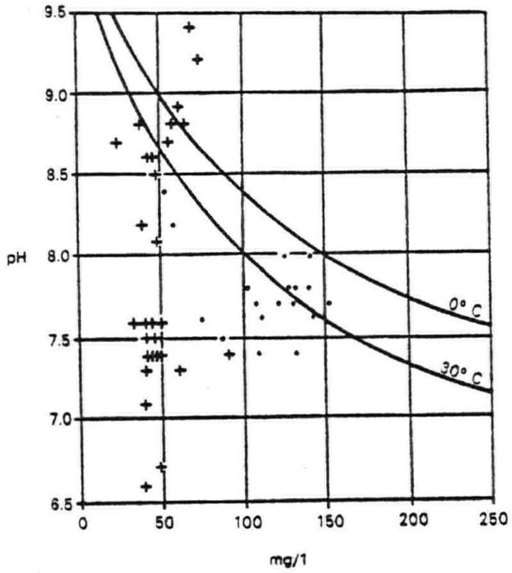

Fig. 2 Picknett (1972) calcite equilibrium curves for appropriate temperature range for water from the Cooleman Plain catchments. Crosses represent calcium hardness of rock catchment runoff; dots represent calcium hardness of soil catchment throughflow.

Removal rates have been calculated in the usual way as $m^3/km^2/y$ or mm/1000y to facilitate comparison with results everywhere. These rates have been calculated for the individual observation periods and meaned for the total times of monitoring. It is useful to start with the mean figures which work out at 9.3 for the rock catchment and 5.3 for the soil catchment. Much the same results are obtained when only matching periods in date are employed for the two catchments (rock 9.7, soil 5.3). Thus the removal rate of the rock catchment is a little less than twice as much as that from the soil catchment. The error due to soil storage changes cannot be great because the ratio is almost identical when unbroken observations from 17/11/75 to 23/9/76 are used on their own (rock 7.7, soil 4.3).

Thus the greater solute concentrations of the soil catchment are outbalanced by loss of water through transpiration and greater evaporation. This interpretation is supported by the seasonal course of removal rates (Fig. 1, f & g) and also by the average removal rates for two periods of unbroken observations, one in winter and one in summer. From 18/2/76 to 25/9/76, the rock catchment rate was 6.9 and the soil rate was 5.3, 77% of the former, whereas over the period of 8/10/76 to 14/2/77 the soil rate was 4.1, 32% of the rock rate of 12.7. Reduced evapotranspirational loss in the winter period compared with the summer period explains the difference.

CONCLUSION

The results of 9.5 mm/1000y from the bare karst and 5.3 from the soil covered karst may be compared with values estimated for the whole superficial zone of this karst in the comparable precipitation years of 1966-7 and 1968-9. Shallow cave drips indicated that 74% of the limestone removal from Cooleman Plain came from the superficial zone, amounting to 30 mm/1000y in the former year and 21 in the latter. There is considerably less bare karst at Cooleman Plain than covered karst, perhaps one quarter of it. The measure obtained from the artificial soil catchment must be below the average loss from the soil and the soil/rock interface over the Plain as a whole. If an underestimate of 50% be allowed, increasing the soil value to 8.0 in this way and allowing for a 1 to 5 area proportion for the two categories of surface, a mean figure of 8.3 results for the surface loss as a whole. Applying this to the earlier periods, subtraction leaves about 23 mm/1000y in 1966-7 and 13 mm/1000y in 1968-9 to be removed from joints, etc. in the uppermost part of the bedrock. This makes it the largest single contribution to the local karst denudation. There is broad correlation between this crude estimate and the findings of Atkinson and Smith (1976) for the Mendip Hills of England.

That higher concentrations obtain in the soil water compared with those from the rock runoff is nothing new, though figures for periods as long as the one recorded here are not common from such micro-environments. Usually this effect is inferred from the averages of hardness of water of various types, chiefly springs and rivers, in different environments, e.g. Fig. 5.7 in Atkinson and Smith (1975) where Arctic/Alpine areas with little soil are compared with soil covered temperate and tropical areas, the former having a lower mean hardness. However, recently Woo and Marsh (1977) have shown how vegetation enhances the hardness of a small stream in a limestone catchment in the high Arctic of Ellesmere Island by the addition of soil throughflow water. They claim that limestone solution is increased in this way. Nevertheless there is no determination of comparative discharges from vegetated and unvegetated areas to prove this claim unquestionably.

The importance of evapotranspirational loss in solution systems has so far been appreciated on the wider basis of the relation of karst to different climatic zones. Thus Corbel stressed how it reduced the effectiveness of rainfall in tropical climates compared with cool climates. But its possible impact on the internal details of solution systems does not seem to have been investigated so far. Despite the crudity of the design of the experiment reported here, a crudity exaggerated by the vicissitudes of its operation, there is a *prima facie* case that, within a climate where at least seasonally evapotranspirational loss may be high, bare karst may be subject to as high or even higher rate of solutional attack from rainfall falling on it as covered parts of the same karst. However, it does not follow from this that the bare karst will be lowered faster than the soil-covered karst because there is an export of still aggressive water from the former to the latter, not all being lost into joints in the bare areas. Part is so lost, nevertheless, and the consequential differential efficiency of the two catchments because of more and less rapid loss of water into the bedrock underlines the mechanism whereby limestone catchments as a whole achieve greater hydrological efficiency as measured by the discharge/rainfall ratio than neighbouring non-karst catchments. This characteristic was one which the notable French hydrologist, Maurice Pardé, drew attention to more than once. There is thus a strong case for better experiments than this recounted here to be pursued in appropriate climates.

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A LATE PLEISTOCENE HUMAN TOOTH FROM TORNEWTON CAVE, DEVONSHIRE, ENGLAND

by C.B. Stringer and Rosemary Powers

SUMMARY

The dating of a hitherto undescribed human incisor from Tornewton cave is discussed. The tooth is briefly described and compared metrically with late Upper Pleistocene and recent lower lateral incisors. Its morphology and size are consistent with the associated late Upper Pleistocene fauna and Upper Palaeolithic artefacts.

In 1953 a human tooth was discovered during excavations at Tornewton cave in the Torbryan valley, Devonshire (Sutcliffe and Zeuner, 1962). The tooth was presented to the British Museum (Natural History) by Mr. S.R. Willing and was registered as a probable lower right lateral incisor (EM 1288). It was excavated from the upper part of the "reindeer stratum" (layer 4), and the associate fauna, including *Rangifer tarandus*, *Crocuta crocuta* and *Dicrostonyx torquatus*, suggests a Devensian age for this deposit. However, this find has not been described and does not appear in current records of British Pleistocene hominid remains (Oakley, Campbell and Molleson, 1971). Several artefacts of Upper Palaeolithic type were also recovered from the "reindeer stratum" and the underlying "elk stratum" and these are now curated in the artefact collection at the British Museum (Natural History). In a recent review of the British Upper Palaeolithic by Campbell (1977), the artefacts from the "elk stratum" were provisionally placed in his "Earlier Upper Palaeolithic" stage, and those from the "reindeer stratum" were placed in his "Later Upper Palaeolithic" stage. On the basis of the data collected for the study, Campbell suggested an approximate age range of 15000-10000 years B.P. for the latter stage. An attempt to obtain an absolute age for the "reindeer stratum" was made by the radiocarbon dating laboratory of the British Museum, but the antler and bone samples submitted by us contained insufficient collagen for dating purposes (R. Burleigh, pers. comm.). Thus for the moment it is still only possible to date the Tornewton human incisor by association to the later Devensian, perhaps between 15000-10000 years B.P.

DESCRIPTION OF THE TOOTH (Figures 1 - 3)

The size and shape of the tooth, and in particular its asymmetry, confirm that this is a lower lateral incisor, since the relatively small crown of the tooth is slightly angled in relation to the axis of the root. Because the incisive edge usually slopes down away from the midline, this tooth is likely to be a right lateral incisor since the mesial crown height would then be expected to be larger, and the longitudinal grooving on the root would be more marked distally, as is the case here (figures 1 to 3). The tooth root is well-developed and flattened mesio-distally. Tooth wear is moderate suggesting an adult, but not aged, individual. There is also some evidence of hypoplasia visible labially and lingually on the enamel close to the cervical margin, indicating a slight deficiency in calcification which may have occurred at about the age of three years.

METRICAL COMPARISONS (Table 1)

As pointed out by several authors there are problems in comparative dental studies caused by differences in the definition of tooth measurements, by differences in tooth wear and preservation, and by the lack of good comparative data (Goose, 1963; Wolpoff, 1971; Frayer, 1978). The majority of published data on Pleistocene hominid teeth are concerned solely with crown lengths, breadths and areas, and comparative data from the last such study of late Pleistocene dental dimensions are displayed in table 1 (Frayer, 1978). In addition some other comparative data have been taken from Black's study of modern human teeth from the United States (Black, 1902) and from our own observations on late Neolithic lower lateral incisors identified by Keith (1924). As can be seen from table 1, the

Fig. 1. Labial view

Fig. 2. Distal view

Fig. 3. Lingual view.

A late Pleistocene human incisor from Tornewton Cave, Devon (photo by P. Richens (B.M.(N.H.).

Table 1

Measurements (in mm) taken on the Tornewton tooth, and comparative data

	Tornewton	Malta Neolithic			Recent Man (Black 1902)		Early Upper Palaeolithic (Frayer 1978)			Late Upper Palaeolithic (Frayer 1978)			Mesolithic (Frayer 1978)		
		Sample	Mean	S.D.	Mean	Range	Sample	Mean	S.D.	Sample	Mean	S.D.	Sample	Mean	S.D.
Maximum height of tooth	19.9	43	20.8	2.65	21.1	18.0 - 27.0									
Maximum crown length (M-D)	4.8	90	5.6	0.57	5.9	5.0 - 6.5	12	6.5	0.62	14	5.5	0.56	81	5.9	0.45
Maximum crown breadth (L-L)	6.4	92	6.2	0.51	6.4	6.0 - 7.5	18	7.0	0.60	20	6.5	0.55	90	6.6	0.39
Maximum root length (M-D)	3.7	89	3.7	0.63											
Maximum root breadth (L-L)	6.5	83	6.1	0.58											
Projected crown height (labial)	7.6	97	8.7	1.69	9.6	7.0 - 12.0									
Projected crown height (lingual)	7.2	96	8.4	1.86											
Length of occlusal surface (M-D)	5.1	95	5.5	0.75											
Breadth of occlusal surface (L-L)	3.0	94	2.3	0.95											
Root height (averaged from labial and lingual surfaces)	12.5	77	11.0	2.82	12.7 (lingual)	11.0 - 17.0									

Tornewton tooth has a relatively low crown length (perhaps partly due to tooth wear) but is nevertheless within the normal range of values for Upper Palaeolithic and more recent teeth.

CONCLUSIONS

Apart from the four fragmentary specimens from Kent's Cavern, the right lower lateral incisor from Tornewton is the only Pleistocene hominid fossil known from a large number of caves excavated in Devonshire. The morphology and dimensions of the tooth are entirely within the range of those of late Pleistocene and recent *Homo sapiens* and are consistent with the supposed late Upper Palaeolithic archaeological associations of the find.

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HISTOPLASMOSIS IN JAMAICAN CAVES

by Alan G. Fincham

ABSTRACT

Histoplasmosis has been demonstrated to result from excessive disturbance of bats in a wet Jamaican cave, in contrast to previous reports of its restriction to dry, dusty caves elsewhere in the tropics.

For many years some of us in the Jamaica Caving Club have been wondering why the mycotic infection, histoplasmosis, caused by the spores of *Histoplasma capsulatum*, appeared to be absent from Jamaican caves whereas it was a major health problem in certain caves in the neighbouring Caribbean island of Puerto Rico (Warren, 1968) and has been recorded from cave sites in Panama (Hasenclever *et al.*, 1967) and in Venezuela (Campins *et al.*, 1956; for a recent review see Frankland, 1974). Indeed, the Puerto Rico Department of Natural Resources had sent their mycologist to Jamaica to visit our caves and investigate this apparent difference. Despite over twenty years of organised caving in Jamaica (the J.C.C. was founded in 1958), no case of the 'cave sickness' had been reported. However, a survey of 308 patients, staff and students at the University Hospital in Jamaica for skin sensitivity to 'histoplasmin', an antigenic extract of the fungus, had shown that some 10% of this group had positive reactions indicating their previous exposure to the infection (Chen & James, 1972).

Our first indications that 'histo' is present in Jamaican caves came in the summer of 1977 when, in company with a visiting party of Liverpool University cavers, five members of the J.C.C. (all five were British expatriates) were given histoplasmin skin tests. Whilst all seven of the newly arrived Liverpool party proved negative, all five J.C.C. subjects showed a strong positive reaction indicating previous (presumably sub-clinical) exposure to the infection.

On January 29th, 1978, two J.C.C. members escorted a party of twenty-six people (including several who had done some previous caving) into the St. Clair Cave in the parish of St. Catherine (Fincham, 1977). Twentytwo of the party were members of the Jamaica Natural History Society and wished to visit a bat colony cave, and St. Clair is perhaps the most populous in the island, boasting some nine different species of bats. It had also received several previous visits from cavers, bat biologists and from the Natural History Society itself in 1954.

An open collapse entrance some 10 metres across leads down over a boulder fall into the Entrance Gallery and thence to a further slope leading to the Main Passage of the cave; a fine river passage, active only in flood conditions. The party was led 'downstream' for some 1500 ft and then returned slowly to the entrance. Meanwhile, some of the group went upstream to enter The Inferno passage, the principal bat roosting area. Exploration of The Inferno is something of a collector's piece; a chest-deep wade through a canal of fermenting guano slosh amid a steady rain of air borne excrement being the prelude to delights to come; but that is another story!

The Natural Historian party returning to the Entrance Gallery were "most impressed" by the winged hordes thus dislodged from their daily sleep and they reported dense clouds of bats creating aerial turbulence and a rain of excrement. The whole party left the cave after some four hours underground.

Some fourteen days later reports of sickness, chesty coughs, and fever, among persons who had been on this trip began to emerge, and some of those who sought medical aid were sent to chest X-ray. Initially, there were some wrong diagnoses ranging from pneumonia, T.B., to acute disseminated carcinoma, but shortly 'the penny dropped' and it became clear that all of these persons had been on the caving trip to St. Clair Cave and had histoplasmosis, a condition never before recognised in Jamaica. In all, twenty-five of the total party of twenty-eight persons showed some symptom of the infection, including a woman and her son, aged four years, who had remained at the entrance to the cave. Several were off work for a while and one case was hospitalised for five weeks. All have now recovered.

Table 1

Summary of principal reports of cave-contracted histoplasmosis

Cave	Country	Year	Persons	Cases#	Bats*	Guano	Wet	Dry	Reference
Forman Bluff	U.S.A.	1947	25	21	?	?		+	Washburn et al.(1948)
Tingo Maria	Peru	1935 -	++	++	Oil birds	++	?	?	Rosell (1955)
Potgietersrust	S.Africa	1953	4	3	?	++		+	Murray et al. (1957)
Thabezibi	S.Africa	1953	4	4	?	++		+	Murray et al.(1957)
'Pothole'	S.Africa	1953	7	7	+	+		+	Murray et al.(1957)
Johnsons Hole	S.Africa	1953	?	7+	?	?		+	Murray et al.(1957)
Sarare	Venezuela	1954	13 5	7 1	++	++	+		Campins et al.(1956)
Urungwe	S. Rhodesia	1955	3	2	++	++	?	?	Dean (1957)
Amboni	Tanzania	1957	2	1	++	++	?	?	Mason-Bahr (1958)
Curium Labyrinth	Cyprus	1960	?	2	+	?		+	Stoker (1964)
Ulster Caves	S. Rhodesia	1960	13	3	?	++	±		Gelfand (1962)
Aguas Buenas	Puerto Rico	1963 1968	14 8	13 6	++	++	+	+	Warren (1968)
Madden Lake	Panama	1965	7	5	++	++	+		Hasenclever (1967)
Church Cave	Australia	1972	6	6	?	++		+	Isbister et al.(1976)
Coy Coy	Venezuela	1973	7	5	?	++	?	?	Frankland (1974)
Cave shelter	Cuba	1974	?	?	++	++		+	Chang-Puga (1974)
St. Clair	Jamaica	1978	28	25	++	++	+		This report.

* Bats present and disturbed by explorers. # Or proven asymptomatic conversion to histoplasmin +ve.
A query ('?') indicates that the published data is insufficient to determine the factor indicated.

A full clinical study of this outbreak of histoplasmosis was carried out (coordinated by Dr. M. Lowe of the Jamaica National Chest Hospital) and included physical and radiological examinations, serology (complement fixation and immuno-electrophoresis) and following-up histoplasmin skin tests. Twenty-one of the cases showed abnormal chest X-rays and twenty-four had positive serological diagnoses. Of the party of twenty-eight persons, two had previously visited St. Clair Cave, while nine had limited caving experience elsewhere, not necessarily in tropical caves.

In cooperation with the Jamaican Publich Health authorities and Dr. L. Ajello, Director of Mycology of the U.S. Centre for Disease Control, Atlanta, the J.C.C. has assisted with the collection from within the cave of soil samples and *Histoplasma capsulatum*, (var. *capsulatum*) has now been isolated from one of the samples. It is intended that this study will be extended to other guano caves in the island to determine the extent of the fungal contamination.

So histoplasmosis is present in Jamaica after all, and does present a hazard to histoplasmin-negative cavers. The Public Health authorities have declared the cave closed:warning notices have been posted. The incident underlines the already recognised hazard to cavers exploring certain tropical guano caves. Routine histoplasmin testing of members of caving parties visiting tropical caves, before and after their visits, would prove interesting and an expedition leader would be wise to employ only histoplasmin-positive cavers in the exploration of known or probable sites of infection. The Jamaica Caving Club is having to alert all newcomers, who may be histoplasmin-negatives, to this hazard and would deter such cavers from visiting St. Clair Cave in particular.

Amongst several points of interest arising out of this incident one is that 'classically' (e.g., Foreman Bluff Cave; Washburn *et al.*, 1948) and in the case of some more cave infections, e.g. Aguas Buenas Caves, Puerto Rico (Warren, 1968), Church Cave, New South Wales, Australia (Isbister *et al.*, 1976), Curium Labyrinth, Cyprus (Stoker, 1964), the cave conditions have been described as dry and dusty under which conditions it is suggested, spores of the fungus are inhaled and set up infection in the lungs. However, St. Clair Cave can in no way be considered in this group; rather it is wet and soggy; conditions in which the prevalence of air-borne spores might be questioned.

The histoplasmosis organism shows two phases of growth; a sporing phase and a vegetative 'yeast cell' phase. It is in this latter form that it is present in infected animals and can lead to serious systematic infection if the cells become disseminated in the body. It has been shown (Klite & Diercks, 1965) that infected bats shed the yeast cells into the intestinal contents and thence into the feces. Thus, whilst the conditions in St. Clair Cave may not be suitable for the air-borne spread of spores it is possible that the infection might be transmitted directly by inhalation of yeast cells in the rain of bat excreta. The absence of clinical infections from previous visits to the cave be large parties, probably including non-immune persons, might be due to the bats not being so greatly disturbed. Cases of infection from wet guano caves have previously been recorded (Shacklette & Hasenclever, 1968; Campins *et al.*, 1956) and frequently infections have occurred when large bat colonies have been disturbed (Table 1). Inhibition of spore dispersal in wet caves has previously been suggested (Disalvo *et al.*, 1970).

Thus, it appears that wet guano caves can present as serious a hazard to cavers as the more widely accepted dry dusty conditions, and that this hazard may be greater if bats are greatly disturbed. This hypothesis as yet requires some onsite experimentation to explore it further.

That several members of the J.C.C. proved to be histoplasmin-positive without any recollection of an associated illness, is in conformity with recent observations (Frankland, 1974) which show that such a transformation from histoplasmin negative to positive is common. This point is further emphasized by the experience of the Liverpool University party, noted above, who were all found to have converted to histoplasmin-positive on return to U.K. (M. Rogers, pers. comm.). Of this party only two persons had entered St. Clair Cave, and that was towards the end of their visit, thus the infection appears to have originated in earlier cave visits of which Oxford and Windsor Caves appear as prime suspects.

Finally, one may note that of the party of twenty-six persons who entered the cave, the three who showed no clear clinical symptoms were all Jamaican resident cavers; including the author. This seems to verify what cavers have known for years; 'wallowing around in muck is good for you'; at least, in a controlled way.

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Index to Volume 5

1978

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